National Aeronautics and Space Administration

Wings In Orbit

Scientific and Engineering Legacies of the Space Shuttle

Foreword: John Young
Robert Crippen

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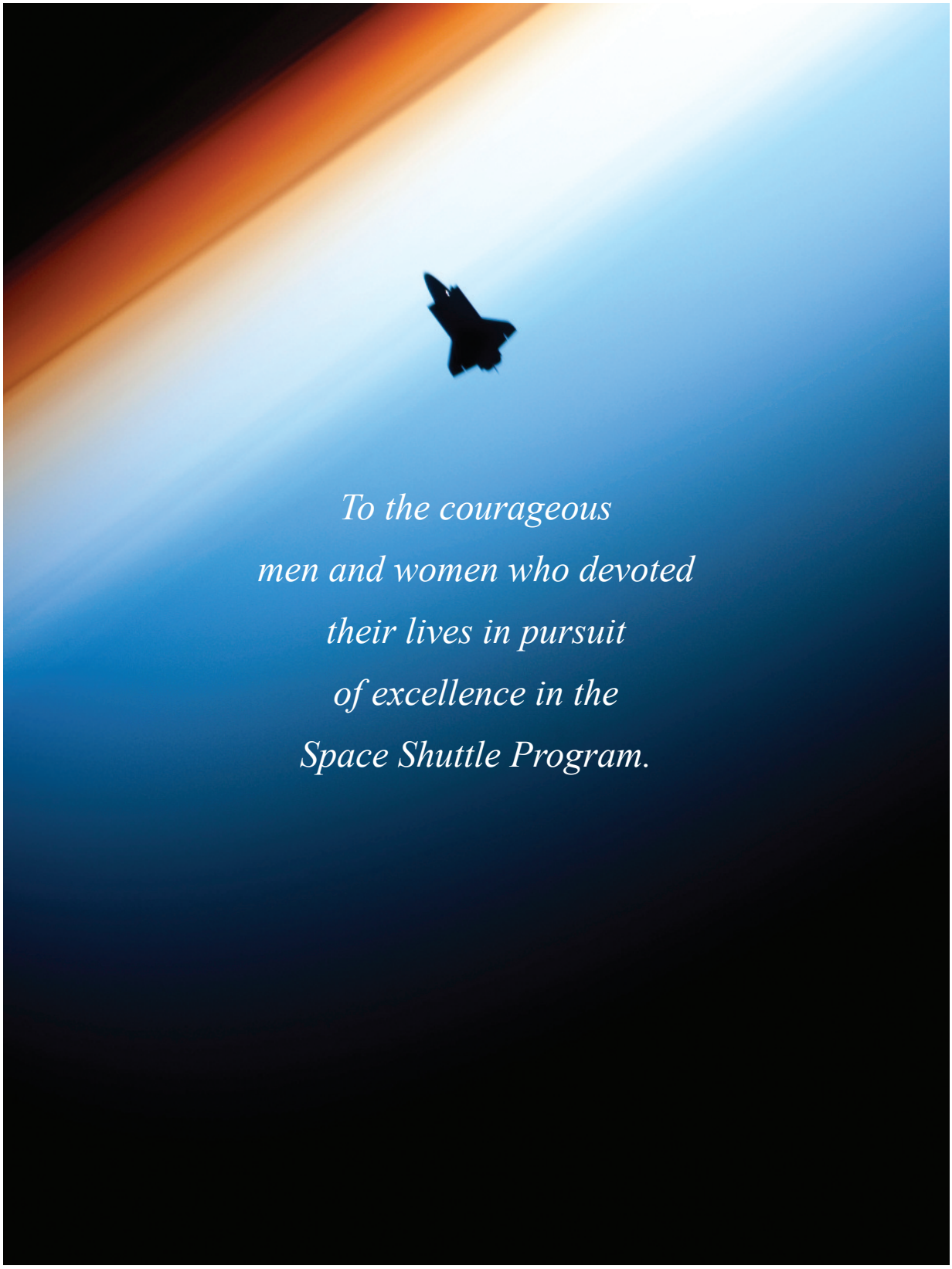
COVER PHOTOS

Front: *View of Space Shuttle Endeavour (STS-118) docked to the International Space Station in August 2007.*

Back: *Launch of Space Shuttle Endeavour (STS-130) during the early morning hours en route to the International Space Station in February 2010.*

Spine: *A rear view of the Orbiter Discovery showing the drag chute deployed during the landing of STS-96 at Kennedy Space Center in May 1999.*


To the courageous
men and women who devoted
their lives in pursuit
of excellence in the
Space Shuttle Program.

Foreword

John Young
STS-1 Commander

Robert Crippen
STS-1 Pilot

We were honored and privileged to fly the shuttle's first orbital flight into space aboard Columbia on April 12, 1981. It was the first time anyone had crewed a space launch vehicle that hadn't been launched unmanned. It also was the first vehicle to use large solid rockets and the first with wings to reenter the Earth's atmosphere and land on a runway. All that made it a great mission for a couple of test pilots.

That first mission proved the vehicle could do the basics for which it had been designed: to launch, operate on orbit, and reenter the Earth's atmosphere and land on a runway. Subsequent flights proved the overall capability of the Space Shuttle. The program went on to deploy satellites, rendezvous and repair satellites, operate as a microgravity laboratory, and ultimately build the International Space Station.

It is a fantastic vehicle that combines human operations with a large cargo capability—a capability that is unlikely to be duplicated in future vehicles anytime soon. The shuttle has allowed expanding the crew to include non-pilots and women. It has provided a means to include our international partners with the Canada arm, the European Spacelab, and eventually the Russians in operation with Mir and the building of the International Space Station. The station allowed expanding that international cooperation even further.

The Space Shuttle Program has also served as an inspiration for young people to study science, technology, engineering, and math, which is so important to the future of our nation.

The Space Shuttle is an engineering marvel perhaps only exceeded by the station itself. The shuttle was based on the technology of the 1960s and early 1970s. It had to overcome significant challenges to make it reusable. Perhaps the greatest challenges were the main engines and the Thermal Protection System.

The program has seen terrible tragedy in its 3 decades of operation, yet it has also seen marvelous success. One of the most notable successes is the Hubble Space Telescope, a program that would have been a failure without the shuttle's capability to rendezvous, capture, repair, as well as upgrade. Now Hubble is a shining example of success admired by people around the world.

As the program comes to a close, it is important to capture the legacy of the shuttle for future generations. That is what "Wings In Orbit" does for space fans, students, engineers, and scientists. This book, written by the men and women who made the program possible, will serve as an excellent reference for building future space vehicles. We are proud to have played a small part in making it happen.

Preface and Acknowledgments

"... because I know also life is a shuttle.
I am in haste; go along with me..."

– Shakespeare, *The Merry Wives of Windsor*, Act V Scene 1

We, the editors of this book, can relate to this portion of a quote by the English bard, for our lives have been entwined with the Space Shuttle Program for over 3 decades. It is often said that all grand journeys begin with a small first step. Our journey to document the scientific and engineering accomplishments of this magnificent winged vehicle began with an audacious proposal: to capture the passion of those who devoted their energies to its success while answering the question "What are the most significant accomplishments?" of the longest-operating human spaceflight program in our nation's history. This is intended to be an honest, accurate, and easily understandable account of the research and innovation accomplished during the era. We hope you will enjoy this book and take pride in the nation's investment in NASA's Space Shuttle Program.

We are fortunate to be a part of an outstanding team that enabled us to tell this story. Our gratitude to all members of the Editorial Board who guided us patiently and willingly through various stages of this undertaking.

Acknowledgments: We are grateful to all the institutions and people that worked on the book. (See appendix for complete list.) Each NASA field center and Headquarters contributed to it, along with many NASA retirees and industry/academic experts. There are a few who made exceptional contributions.

The following generously provided insights about the Space Shuttle Program: James Abrahamson, Arnold Aldrich, Stephen Altemus, Kenneth Baldwin, Baruch Blumberg, Aaron Cohen, Ellen Conners, Robert Crippen, Jeanie Engle, Jack Fischer, William Gerstenmaier, Milton Heflin, Thomas Holloway, Jack Kaye, Christopher Kraft, David Leckrone, Robert Lindstrom, William Lucas, Glynn Lunney, Hans Mark, John Mather, Leonard Nicholson, William Parsons, Brewster Shaw, Robert Sieck, Bob Thompson, J.R. Thompson, Thomas Utsman, Edward Weiler, John Young, and Laurence Young.

We also gratefully acknowledge the support of Susan Breeden for technical editing, Cindy Bush for illustrations, and Perry Jackson for graphic design.

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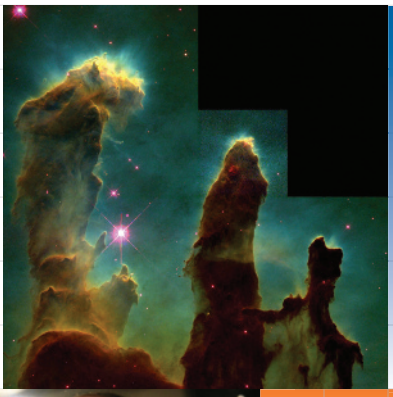

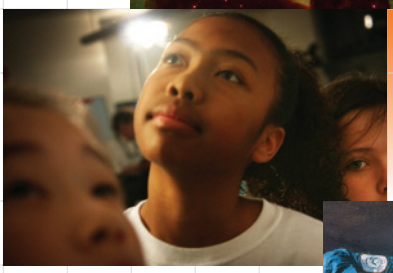

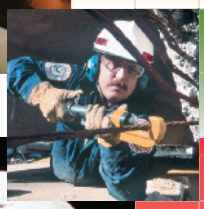

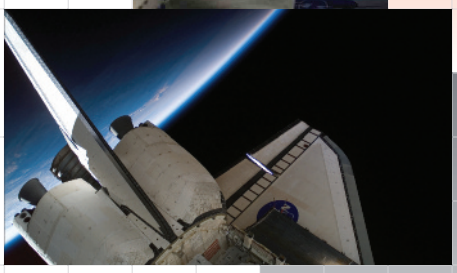

Editorial Board

Witnessing the Launch of the Shuttle Atlantis

Howard Nemerov
Poet Laureate of the United States
1963-1964 and 1988-1990

So much of life in the world is waiting, that
This day was no exception, so we waited
All morning long and into the afternoon.
I spent some of the time remembering
Dante, who did the voyage in the mind
Alone, with no more nor heavier machinery
Than the ghost of a girl giving him guidance;

And wondered if much was lost to gain all this
New world of engine and energy, where dream
Translates into deed. But when the thing went up
It was indeed impressive, as if hell
Itself opened to send its emissary
In search of heaven or "the unpeopled world"
(thus Dante of doomed Ulysses) "behind the sun."

So much of life in the world is memory
That the moment of the happening itself—
So much with noise and smoke and rising clear
To vanish at the limit of our vision
Into the light blue light of afternoon—
Appeared no more, against the void in aim,
Than the flare of a match in sunlight, quickly snuffed.

What yet may come of this? We cannot know.
Great things are promised, as the promised land
Promised to Moses that he would not see
But a distant sight of, though the children would.
The world is made of pictures of the world,
And the pictures change the world into another world
We cannot know, as we knew not this one.

Introduction

Charles Bolden

It is an honor to be invited to write the introduction for this tribute to the Space Shuttle, yet the invitation presents quite an emotional challenge. In many ways, I lament the coming of the end of a great era in human spaceflight. The shuttle has been a crown jewel in NASA's human spaceflight program for over 3 decades. This spectacular flying machine has served as a symbol of our nation's prowess in science and technology as well as a demonstration of our "can-do" attitude. As we face the fleet's retirement, it is appropriate to reflect on its accomplishments and celebrate its contributions. The Space Shuttle Program was a major leap forward in our quest for space exploration. It prepared us for our next steps with a fully operational International Space Station and has set the stage for journeys to deep-space destinations such as asteroids and, eventually, Mars. Our desire to explore more of our solar system is ambitious and risky, but its rewards for all humanity are worth the risks. We, as a nation and a global community, are on the threshold of taking an even greater leap toward that goal.

All the dedicated professionals who worked in the Space Shuttle team—NASA civil servants and contractors alike—deserve to be proud of their accomplishments in spite of the constant presence of skeptics and critics and the demoralizing losses of Challenger (1986) and Columbia (2003) and their dedicated crews. Some of these scientists and engineers contributed to a large portion of this book. Their passion and enthusiasm is evident throughout the pages, and their words will take you on a journey filled with challenges and triumphs. In my view, this is a truly authentic account by people who were part of the teams that worked tirelessly to make the program successful. They have been the heart, mind, spirit, and very soul that brought these amazing flying machines to life.

Unlike any engineering challenge before, the Space Shuttle launched as a rocket, served as an orbital workstation and space habitat, and landed as a glider. The American engineering that produced the shuttle was innovative for its time, providing capabilities beyond our expectations in all disciplines related to the process of launching, working in space, and returning to Earth. We learned with every succeeding flight how to operate more efficiently and effectively in space, and this knowledge will translate to all future space vehicles and the ability of their crews to live and work in space.

The Space Shuttle was a workhorse for space operations. Satellite launching, repair, and retrieval provided the satellite industry with important capabilities. The Department of Defense, national security organizations, and commercial companies used the shuttle to support their ambitious missions and the resultant accomplishments. Without the shuttle and its servicing mission crews, the magnificent Hubble Space Telescope astronomical science discoveries would not have been possible. Laboratories carried in the payload bay of the shuttles provided opportunities to use microgravity's attributes for understanding human health, physical and material sciences, and biology. Shuttle

research advanced our understanding of planet Earth, our own star—the sun—and our atmosphere and oceans. From orbit aboard the shuttle, astronaut crews collected hundreds of thousands of Earth observation images and mapped 90% of Earth's land surface.

During this 30-year program, we changed dramatically as a nation. We witnessed increased participation of women and minorities, the international community, and the aerospace industry in science and technology—changes that have greatly benefitted NASA, our nation, and the world. Thousands of students, from elementary school through college and graduate programs, participated in shuttle programs. These students expanded their own horizons—from direct interactions with crew members on orbit, to student-led payloads, to activities at launch and at their schools—and were inspired to seek careers that benefit our nation.

International collaboration increased considerably during this era. Canada provided the robotic arm that helped with satellite repair and served as a mobile crew platform for performing extravehicular activities during construction of the International Space Station and upgrades and repairs to Hubble. The European Space Agency provided a working laboratory to be housed in the payload bay during the period in which the series of space laboratory missions was flown. Both contributions were technical and engineering marvels. Japan, along with member nations of the European Space Agency and Canada, had many successful science and engineering payloads. This international collaboration thus provided the basis for necessary interactions and cooperation.

My personal change and growth as a Space Shuttle crew member are emblematic of the valuable contribution to strengthening the global community that operating the shuttle encouraged and facilitated. I was honored and privileged to close out my astronaut career as commander of the first Russian-American shuttle mission, STS-60 (1994). From space, Earth has no geographic boundaries between nations, and the common dreams of the people of these myriad nations are realizable when we work toward the common mission of exploring our world from space. The International Space Station, the completion of which was only possible with the shuttle, further emphasizes the importance of international cooperation as nations including Russia, Japan, Canada, and the member nations of the European Space Agency join the United States to ensure that our quest for ever-increasing knowledge of our universe continues to move forward.

We have all been incredibly blessed to have been a part of the Space Shuttle Program. The "Remarkable Flying Machine" has been an unqualified success and will remain forever a testament to the ingenuity, inventiveness, and dedication of the NASA-contractor team. Enjoy this book. Learn more about the shuttle through the eyes of those who helped make it happen, and be proud of the human ingenuity that made this complex space vehicle a timeless icon and an enduring legacy.